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TRANSLATION

PENDULUM WITH LIQUID FILLER-INSTRUMENT TO DEMONSTRATE DIURNAL ROTATION OF THE EARTH

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PENDULUM WITH LIQUID FILLER-INSTRUMENT TO DEMONSTRATE DIURNAL ROTATION OF THE EARTH

By

V. Ya. Gavrik

Evidences of the rotation of the Earth are based on the fact, that any body, moving relatively to the Earth, is affected by the Coriolis force, with which is taken into consideration the effect of Earth's rotation on the relative movement of body. The effect of Coriolis forces lies in the fact, that a body, moving on the rotating Earth, will either deviate in direction, perpendicular to the instantaneous value of its relative speed, or exert a proper pressure on the connection. This effect is most clearly demonstrated in the behavior of moving liquids, exerting a pressure on solid body walls tangent to them in direction of action of the Coriolis force (so-called Bear law). Consequently it is natural that the use of moving liquids is employed in demonstration instruments. But in the Grammel review 1 among numerous examples of experimental proof of the diurnal rotation of the Earth there is a single example of a hydraulic experiment (par. 10, p.356) of Pero and Komba, based on the law of surfaces in application to liquid flows.

A pendulum moves under the effect of a gravitational force, due to the mass of the Earth. Its movement also reflects the Coriolis force, due to diurnal rotations of the Earth. The latter is relatively low as result of low angular velocity of Earth's rotation. The movement of the pendulum is promoted by combined actions of two forces, not depending upon the experimentator, of terrestrial origin: gravity and Coriolis. To demonstrate the diurnal rotation of the Earth the problem consists in the creation of pendulums, sensitive to the action of Coriolis force.

It is possible to suggest pendulums with solid load, introduced by Fuko and Pomekhohov[2]. The visible displacement of the pendulum with respect to the Earth is observed as a rotation of a rolling surface at constant angular speed (Fuko

pendulum) or with variable (Poshekhonov pendulum).

To successfully observe the effect are needed Fuko pendulums of larger dimensions. And so, the Paris Fuko pendulum is 67 m long and weighs (a load) 28 kg, the Leningrad unit is 96 m long and has a load of 54 kg. The preparation of unique Cardan suspensions of demonstration pendulums enabled to reduce their length to several meters (at a load of about 30 kg). And so, the Fuko pendulum of the Moscow Planetarium is 4.6 m long, of the Volgograd and Leningrad Planetariums - about 7 m.

The Poshekhonov pendulum represents a bar with weights and frame, capable of rotating about an azimuthal axis in direction of Earth's rotation.

Pendulums with solid loads, introduced at various times by Fuko and Poshekhonov, due to structural and operational difficulties have not attained broad application.

One of the ways of increasing the quality of pendulum instruments, intended to demonstrate the diurnal rotation of the Earth, is the use in then of non-wettable liquids with free surface. Experience shows, that the sensitivity of the Fuko pendulum to the effect of the diurnal rotation of the Earth (at unchanged weight of load and length of suspension) rises sharply when the solid load is replaced by a compound load: solid flask, partially filled (to the middle) with a heavy non-wettable liquid. The observed rise in demonstration qualities of such a pendulum is explained by the fact, that its load consists of masses, differing in their state of aggregation (liquid and solid body), which under the effect of Coriolis forces do behave differently. This difference lies in the fact that during the displacement of the center of mass of the solid body, the disposition of atoms (or molecules) of the body relative to it remains unchanged. In liquid it may change. That is why the use of a combined liquid-solid load in a pendulum, intended to demonstrate the diurnal rotation of the Earth, allows to utilize a parametric pendulum with liquid filler, distinguished by accessiblity (in comparison with Fuko pendulum) and simplicity (in comparison with Poshekhonov Pendulum).

Under the effect of the Coriolis component force of inertia the filler periodically, with a frequency of pendulum oscillations, changes its form within the shell, retaining its volume unchanged. The form and volume of the shell remain unchanged. The filler, following the movement of the pendulum, is displaced in the shell, trying to situate its free surface perpendicularly to the instantaneous value of the direction of the geometric sum of gravitation and Coriolis forces, forces, and the component load of the pendulum as result of periodic change in mass distribution acquires an acceleration in horizontal direction perpendicularly to the plane of rolling, i.e. in azimuthal plane. In other words the pendulum shows the rapidly progressing deformation of the initial rolling plane with its simultaneous turning as result of periodic change in center of mass of the component load.

For a pendulum with solid load is introduced a concept of given length l_0, determinable as

$$l_0 = \frac{J}{Ml}, \qquad (1)$$

where l - distance from point of suspension to center of gravity, M-mass of pendulum and J - moment of inertia of the pendulum relative to the axis of rotation, determinable by formula

$$J = \sum_{i=1}^{n} m_i r_i^2, \qquad (2)$$

where n-number of particles, m_i mass of i particle and r_i-its distance from point of pendulum suspension. For a pendulum with solid load the value l_0 and J remain unchanged in the process of its oscillation. For a pendulum with component load they change in the process of oscillation and are expressed by ratios

$$l_0 = l_{0T} + l_{0c} = \frac{J_T}{Ml} + \frac{J_{\text{ц.с}}}{Ml} \qquad (3)$$

$$J = J_T + J_{\text{ц.с}}. \qquad (4)$$

where l_{0T} and J_T - their constant components, pertaining to the shell, l_{0c} and $J_{ts.s}$ their variable components, pertaining to the filler. If for a pendulum with component load l_{0i} would designate the given length during the effect of the

gravity force and l_{o2} - during the effect of gravitation and Coriolis forces and respectively by $L_{op.s1}$ and $l_{op.s2}$ - for the liquid filler, then we will obtain, that under the effect of the gravitation force only

$$l_{01}=l_{0т}+l_{0п.с1} \tag{5}$$

and under the effect of gravitation and Coriolis forces

$$l_{02}=l_{0т}+l_{0п.с2} \tag{6}$$

In the role of criteria, characterizing the demonstrating qualities of a pen dulum with component load, it is convenient to select the difference $\Delta l_o = l_{o1} - l_{o-2}$, which according to formulas (5) and (6) and with consideration of (3) equals

$$\Delta l_0=\frac{J_{0п.с1}-J_{0п.с2}}{Ml}, \tag{7}$$

where $J_{ip.s1}$- static moment of inertia of the filler in equilibrium position and $J_{op.s2}$- moment of inertia of the filler, the form of which was changed by the effect of the Coriolis force.

Considering, that according to (7) the change in given length of the pendulum with component load depends on the change of given filler length (active factor) at unchanged given length of the shell (passive factor), we arrive at a conclusion, that in preparing such a pendulum it is necessary to make efforts that the mass of the filler should be possibly greater in comparison with the mass of the shell (suspension mass can be disregarded).

In this way, as result of change in mass distribution of the component load at the time of pendulum movement the latter executes parametric oscillations under the effect of Coriolis forces. The parameter appears to be the given length of the pendulum, periodically changing under the effect of Coriolis forces, changing the form of the moving filler with free surface, and consequently, also the moment of inertia of the pendulum. By the presence of parametric oscillations does the proposed pendulum differ from Fuko and Poshekhonov pendulums, executing forced oscillations.

Parametric oscillations, as is known, are executed much easier, the greater the change in parameter and the smaller the energy losses in the system on account of friction or resistance. Consequently, to reduce the time of increasing the effect to visually observed value it is necessary to try and reduce energy losses on account of suspension friction and resistance to azimuthal displacement of component load, and also on account of friction during the displacement of the liquid with respect to the flask. The presence of filler friction against the flask and the the lagging in its displacement relative to the force may distort the experimental results, and the imperfection of the suspension may lead to additional deformations of same during the rolling of the pendulum. In this case the effect, observed in the experiment, may depend only in a slight degree upon the Coriolis forces. That is why the filler must have as much as possible a greater free surface and non-wettability with respect to the material of the shell, and the suspension should be elastically-symmetrical relative to the vertical of the suspension.

A favorable combination appears to be the use of mercury, having greater specific weight and table tennis (ping-pong) balls. The latter are of low weight ($\approx$ 2.5 g) at considerable volume ($\approx$ 15 cm3 liquid at half filling) and greater strength (filled with water when falling from a height of 2.4m, remain in tact). They submit easily to mechanical treatment, do not contaminate the filler, are inexpensive and can be obtained in any amount.

To make a pendulum in the ball are made (drilled or burned through) two holes of different diameters spaced at a small distance from each other and through the larger one the ball is filled to half (to the middle) with a non-wettable liquid, best of all, with mercury. Then some water is added (to prevent possible evaporation of the mercury). On one end of the suspension (string or other thin metal wire) 0.25 - 0.5 m in length, is fastened a rubber ball, the diameter of which corresponds to the diameter of the larger opening in the ball. The free

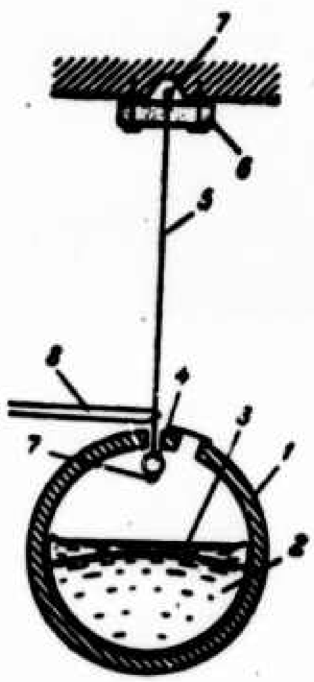
end of the suspension is then run through the larger and smaller openings of the ball and the larger opening is pasted up. The free end of the suspension is passed, with the aid of a needle, through a rubber plate of about 1 cm in thicknews (e.g. through a school eraser) and, after removing the needle, it is tied in a knot. If the rubber plate is then fastened horizontally at the height of greater length of pendulum, then the thread of the suspension, fastened by knots in the lower part of the ball and in the upper side of the plate will tie the load with point of suspension not by rigid fastenings, but by means of elastic (rubber) symmetrical buffers, reducing to a minimum the additional deformations of the suspension, thus increasing the relative effect of the Coriolis force.

A schematic drawing of a pendulum with component load is shown in the illustration, where it is designated: 1-shell; 2-filler (mercury); 3-water; 4-buffer rubber ball; 5-suspension thread; 6-buffer rubber; 7-knots of suspension thread. To start, the pendulum is burned through thread 8, which holds it in initial deflected position. Such a pendulum at an initial angle of inclination of about 10° assures within 3-5 min after the starting at a latitude of about 60° (in Leningrad) a direct observation of the effect of Earth's rotation on it: its rolling plane becomes deformed and turns in one direction trying to settle in plane of geographic parallel (in East-West direction) and in this aspect appears to be a peculiar compass. The effect appears most vividly when the initial plane of pendulum oscillation is in direction, close to North-South direction, at which the displacing effect of the Coriolis force on the filler appears to be maximum.

Such a pendulum from a table tennis ball with mercury half filler and mentioned buffer suspension assures the observation of the effect at a suspension length of 0.25 - 0.5 m.

Observations can be conducted by the shadow of the load, derived under it on a sheet of paper with a system of radial lines from an electric light, situated at the point of pendulum suspension.

In this way, the pendulum with liquid filler has the ability of accumulating the actions of small Coriolis accelerations, detecting the effect of Coriolis forces on liquid-solid pendulum load, in contrast to Fuko and Poshekhonoc pendulums, demonstrating its effect on a solid load. It appears to be a peculiar compass, indicating direction, perpendicular to true(geographic) meridian.



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